DETERMINING SIMULATION REQUIREMENTS AND IDENTIFYING A COURSE OF ACTION TO MORE EFFICIENTLY SUPPORT ACQUISITION DECISION-MAKING FOR THE CURRENT AND FUTURE FORCE INFANTRY WARRIOR

G. L. Boylan*, E. S. Tollefson, M. J. Kwinn, Jr, and P. G. Martin

Operations Research Center of Excellence
Department of Systems Engineering
United States Military Academy
West Point, NY 10996 U.S.A

ABSTRACT

Maintaining an edge during this time of unprecedented technological growth requires that the Army field Infantry soldier systems quickly. However, the risk of doing so without some assessment of utility is quite high. Accordingly, the acquisition community must develop its ability to predict the operational effectiveness and benefits of proposed systems with an ever-increasing degree of accuracy. To this end, the Army has resorted to combat simulations. However, the representation of the individual soldier within the context of such simulations has evolved at a markedly slower pace than other representations. In this paper, we will discuss the unique simulation requirements we developed to represent the Infantry soldier in adequate detail, the alternative we recommended to fulfill those requirements and support acquisition decision-making, as well as the first phase of implementation of that recommendation and how it will impact the current and future force.

1. INTRODUCTION

One of the primary challenges facing the United States Army acquisition community is that of quickly fielding technologically-advanced equipment to the force. The high cost of doing so brings with it significant risk, as demonstrated by the Crusader artillery and Comanche helicopter programs, both multi-billion dollar programs cancelled within the last two years. Consequently, program managers must be able to reasonably guarantee the utility of their products early in the design phase and continue doing so throughout the product's lifecycle. To that end, the Army has turned to simulation to evaluate the combat effectiveness of its proposed systems.

Unfortunately, the development of technological capabilities, especially with respect to information sharing, is outpacing improvements in current combat simulation capabilities. Moreover, until recently, the focus of the combat modeling community has been on large battlefield platforms and unit-level analyses. As a result, the representation of the individual soldier on the battlefield has not evolved as quickly as other representations. With the face of warfare rapidly shifting to one involving small-unit actions against asymmetric threats coupled with the increasing role of technology at the soldier level, simulation models require unprecedented fidelity in terms of the Infantry soldier entity and his environment.

The Program Executive Office Soldier (PEO Soldier), is the Army program manager for the acquisition of nearly all the items and soldier tactical mission system (STMS) components carried or worn by the Infantry soldier. As such, they require a high-resolution simulation capability to represent the Infantry soldier in enough detail to estimate the operational effectiveness of the products they provide. They have realized that existing simulation capabilities are not up to the task and, in the fall of 2003, commissioned an independent study by the Operations Research Center of Excellence at the United States Military Academy to determine the requirements necessary for such a simulation and to recommend an alternative to address their needs more fully.

This paper will focus on three key areas of that study. First we will emphasize the simulation requirements we developed to represent the Infantry soldier, including a brief background to articulate how we arrived at these requirements using a combination of common systems engineering tools. We will then discuss the alternatives available to PEO Soldier as a means to achieving the decision support they require, focusing on our recommended course of action and its advantages. Finally, we will address the first phase of implementation of that recommendation and how it will impact the current and future force.

2. SIMULATION REQUIREMENTS

2.1 Background

One of PEO Soldier's goals, and the focus of the study, is to identify a simulation package that will provide the means to assess quantitatively the platoon-level operational effectiveness of a new system or component. Thus, the simulation must be at the

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resolution of the individual soldier while providing aggregate measures at the platoon level. This type of simulation system is typically required for the Analysis of Alternatives (AoA) process, which includes an analytical study to determine the operational effectiveness of alternate system proposals. In short, it facilitates adequate comparative analyses to differentiate between proposed system configurations and distribution. To do so efficiently and effectively, the simulation model must represent those inputs and outputs affecting or affected by the STMS being considered, while still producing a valid result. Otherwise, unique aspects of the systems being compared will not factor into the simulation output, potentially resulting in an uninformed decision.

To date, various Army agencies and contractors have recognized the need for such a simulation and have made considerable efforts to address the problem. From our observations, their efforts to identify requirements fall into two approaches. The first is an upgrade-based approach, wherein the recognition of a unique requirement drives changes to an existing (legacy) simulation to meet that need. This is an iterative approach that leads to a continual upgrade cycle, often resulting in numerous concurrent versions of the same software, and is limited by the architecture and design of the software. This process rarely yields a comprehensive set of requirements that fully identifies an organization's needs, a valuable product itself.

The second is a characteristics-based approach whereby an organization identifies its requirements based on the characteristics used to evaluate the system of interest. When we began this project, we too attempted to derive the requirements in this way. Although this approach can yield a comprehensive set of requirements, it has some drawbacks. One is that the characteristic itself may not be well-defined or translate well into simulation requirements. For instance, a commonly-used term for a capability improvement of modern soldier systems is their ability to enhance a soldier's *situational awareness*. Not only is the definition of this term not widely agreed upon, its broad implications make it hard to decompose into requirements. A soldier's situational awareness directly affects, and is directly affected by, other high-level characteristics like mobility, lethality, and survivability, which themselves overlap for many of the soldier's functions. That interdependence complicates the logical decomposition into simulation requirements and is the primary reason we chose another method, which we will discuss in the following section.

2.2 Functional Analysis Methodology

We based our approach to define a set of simulation requirements on the Systems Engineering and Management Process (SEMP), taught in the Department of Systems Engineering at the United States Military Academy (USMA) (McCarthy, McFadden, and McGinnis 2003). The first phase of the process is Problem Definition which involves a consortium of tools and techniques to derive and articulate more fully and accurately the client's need. Such techniques include system decompositions, stakeholder analyses, functional decompositions, analyses of system inputs and outputs, futures analyses, and Pareto-type data analyses. From there, the engineer transforms the required functions of the system into objectives and measures to evaluate those objectives. This *value system* represents the values of the primary stakeholders and provides a basis to evaluate future alternative solutions. For our study, we wished to have, at the end of the Problem Definition phase, a set of simulation requirements that meet PEO Soldier's need.

In this paper, we will focus on our functional and input-output analyses. In developing the requirements necessary to model the Infantry soldier and the impacts/effects of technologically-advanced weaponry and equipment, we conducted a thorough functional decomposition of what the Infantry soldier does as the primary entity of the simulation. At the highest level of our functional decomposition, the two most basic soldier functions involve deciding and acting. We use the term "decide" to indicate any mental process performed by the soldier whereas the term "act" reflects the actions taken by the soldier as a response to the decisions made. The six primary "decide" functions we identified are: assess the situation, make sensing decisions, make engagement decisions, make movement decisions, make communications decisions, and make enabling decisions. The latter five correspond to the five highest-level "act" functions sense, engage, move, communicate, and enable. Figure 2.1 depicts our functional hierarchy at its highest level.

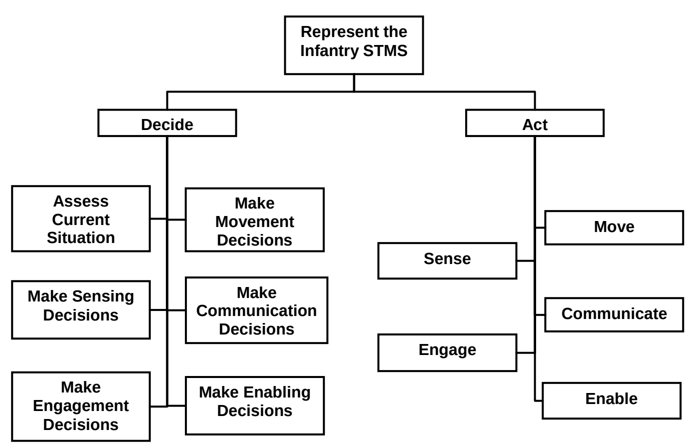

Figure 2.1: The soldier functional hierarchy

Each of the functions depicted in Figure 2.1 have inputs and outputs. The functions themselves provide the means by which the respective inputs are transformed

into outputs. The performance of these functions is affected by soldier attributes, which themselves act as inputs or controls. For example, attributes acting as controls may be rule sets for making a decision, a general knowledge base drawn upon by cognitive processes, or physical constraints affecting performance. Additionally, the process itself can affect or change these attributes. For instance, movement can reduce the soldier's energy level, conducting operations can increase his experience level, and equipment damage can change its physical and performance characteristics. We grouped the attributes into three categories: mission, personal, and equipment. These reflect the soldier's knowledge of his mission and how he is expected to accomplish it, the characteristics of the soldier himself (physical, physiological, psychological, mental, and readiness), and the characteristics of the equipment/weapons/clothing employed by the soldier respectively.

The decide and act modules interact continuously; a soldier assesses his situation, makes a decision based on that assessment, and takes some resulting action, which then leads to another decide/act cycle. Moreover, some of these cycles may be nested within each other. For example, consider the case in which a soldier embarks on a patrol as part of a larger unit (squad or platoon). From the start, he assesses the situation evolving around him. This "assess" function serves as a primary driver for most soldier decision-making and actually involves several assessments that comprise the whole, including appraisals of the mission, enemy situation, friendly situation, environment/battlespace, time available, and neutral/civilian situation. Over the course of the patrol, the soldier engages in various "sensing" decisions and actions as he selects from various methods to search, acquire, and track/designate potential targets and then employs the selected method.

Continuing the previous example, suppose that in the midst of the soldier's "sensing" actions, he encounters an enemy threat which causes him to reassess quickly the enemy situation as it pertains to him. This reassessment generates other decision cycles, such as "communications," "engagement," or "movement" whereby the soldier must decide whether to communicate the situation to the patrol leader, move to or away from the target, and/or engage the target himself. Each of these decisions generates a corresponding action that serves to implement the decision. Even more, the soldier's decision may in fact be a nested compilation of all of these functions, such that he decides to communicate the information higher while he simultaneously decides to move against the target and engage it. In the asymmetry and decentralization of today's battlefield, this is more commonly true as an increasing level of decision/action authority is pushed down to the platoon level and, in some cases, to the individual soldier.

The purpose of most, if not all, soldier tactical mission systems is to arm and equip the soldier with technological advancements that enhance his ability to assess, decide, and act in virtually any battlefield scenario. Therefore, in order to capture properly such behaviors and the impacts of tactical mission systems upon them, any simulation must be able to represent accurately and completely the soldier's ability to decide and act.

2.3 Results

Early in our analysis, we discovered that the simulation requirements flowed from two primary needs: the need for realism and the need for a tool to compare candidate soldier tactical mission systems (STMS). The simulation model has to produce valid outcomes based upon the inputs. This fact is certainly not unique to our study, but is the goal of all combat simulations. But how much realism is required? Resource and technology constraints dictate that we define an appropriate level of fidelity. The answer to that question depends primarily upon the purpose of the simulation, which in our case is to provide a decision aid for comparing STMS configurations and distribution. Therefore, the simulation model must represent those inputs and outputs affecting or affected by the system being considered, while still producing a valid result. Otherwise, unique aspects of the systems being compared will not factor into the simulation output, potentially resulting in an uninformed decision. This is currently the case in existing simulations and the reason PEO Soldier commissioned this study.

Any comparison between systems must consider each system's performance with respect to its desired characteristics. According to an engineering problem statement written for PEO Soldier in 2000 by the Department of Systems Engineering at USMA, the main STMS characteristics are mission capability, survivability, and trustworthiness. Mission capability and survivability further consist of lethality, mobility, protection, communications, and situational awareness. Trustworthiness pertains to system reliability, availability, maintainability, sustainability, and usability. The simulation model, then, must provide measures of the system's performance in terms of those characteristics as outputs.

Analysts use measures of effectiveness (MoE) to evaluate the predicted outcomes for one or more of these characteristics. Likewise, each MoE may depend upon a large number of measures of performance (MoPs), which are lower-level measures that quantify the performance of a specific piece of equipment or human task. As an example, consider characteristic of lethality. A common MoE used to evaluate this characteristic is the total number of enemy kills, whereby a higher level of kills reflects a higher degree of lethality. The MoPs that

affect or influence this MoE might include the weapon rate of fire, accuracy, reliability, human aiming error, target location error, etc. As an extension, it should be apparent that weapon reliability also directly affects system trustworthiness, which reflects the same interdependence between characteristics that led us to decompose by function.

By combining a comprehensive functional decomposition with detailed input-output analyses for every function in the hierarchy, we developed a more complete and accurate picture of desired performance outputs (MoEs) and the MoPs that affect them. This further resulted in identifying unexpected sources of performance contribution that we would have missed using other methods. Thus, for a comparative analysis, our results give PEO Soldier a clearer picture of how their individual systems contribute to the effectiveness of the soldier as a system of systems.

The uniqueness of our approach lay in our deviation from the traditional method of building functional requirements around the concepts of lethality, mobility, survivability, reliability, and situational awareness. While the language throughout the Army is replete with these concepts, we determined that they are not so much functions the soldier performs on the battlefield but rather descriptors of the outputs generated by actions the soldier takes. Moreover, these concepts are most often considered independently of each other when, in fact, they are extensively intertwined, which complicates any logical decomposition. For example, lethality is typically viewed as a function of the soldier's ability to engage and destroy a target. However, when you consider lethality in the broader context of the soldier's battlefield functions, it is plain to see that it is actually a resulting output of many of the actual functions the soldier performs, such as his ability to communicate information about that target to bring other effects to bear, his ability to move quickly and stealthily in order to place himself in a position of greater advantage, and his level of training coupled with his ability to think and employ effectively the weapons/equipment he possesses. Similarly, situational awareness evolves from the functions the soldier performs in assessing the battlefield situation, in communicating/receiving information to and from other personnel/units, in moving around the battlefield to refine the his picture/understanding of the battlespace, and so on.

Thus, it becomes clear that these concepts are quite interconnected; the functions that result in mobility likewise affect the level of situational awareness, which itself has a profound impact on lethality. Lethality is further impacted by the reliability of the STMS, the soldier's ability to employ it, as well as his ability to perform the remainder of his battlefield functions. Accordingly, our approach involved a fresh look at the functions that the Infantry soldier performs in the execution of his battlefield mission. This yielded a comprehensive set of functional requirements that more accurately and fully encapsulates the decide/act cycles that form the core of the soldier's battlefield functionality, which will facilitate a more accurate and complete representation of the soldier in any simulation. This, in turn, sets the conditions by which PEO Soldier can obtain a simulation that facilitates adequate comparative analyses between soldier tactical mission systems. For a complete taxonomy of our simulation requirements, refer to our technical report (reference 3).

3. THE ALTERNATIVES

3.1 Initial Identification and Categorization of Alternatives

After generating our set of simulation requirements, we turned our attention to identifying candidate solutions to the problem. We generated a large number of alternatives that fell into five categories. These categories consisted of: 1) using existing simulation capabilities, 2) using simulation packages currently under development, 3) modifying simulations under development, 4) using a combination of the previous three categories, and 5) creating a new simulation altogether. The first category forces an evaluation of existing simulation technologies to ascertain whether they can presently meet our requirements. The second looks to simulations currently under development to determine whether, based on their projected capabilities, they will address the soldier in the requisite detail. The third involves modifications to the simulations under development in order to make up for any requirements shortcomings and thereby facilitate a more complete representation. The fourth category simply refers to a combination of categories 1, 2, and 3 while the fifth category involves the creation of a new simulation capability from scratch.

3.2 The Screening Process

Within these five categories, not all of the alternatives we initially identified were feasible. Our initial stakeholder analysis revealed several constraints that any candidate solution would have to satisfy in order to merit further consideration. We applied these constraints to remove infeasible alternatives and thereby thin out the selection pool. The applied constraints consisted of:

- The user/analyst must have the ability to alter STMS characteristics within the simulation;
- The user/analyst must have the ability to enter and modify a scenario into the simulation;
- The simulation must be at the resolution of the individual Infantry soldier;

- The simulation software must be high level architecture (HLA) compliant;
- The simulation must be capable of closed-loop (non-human-in-the-loop) execution.

We developed a matrix whereby we screened each of our original alternatives against each constraint. A failure to meet any one constraint eliminated an alternative from further consideration. Figure 3.1 depicts our Feasibility Screening Matrix, which reflects our final list of alternatives. Note that an asterisk (*) in the table represents alternatives considered together for screening purposes (i.e., modified and unmodified simulations under development).

As Fig. 3.1 reflects, our final list of alternatives consisted of the following simulation solutions: Janus, Joint Conflict and Tactical Simulation (JCATS), One Semi-Automated Forces (OneSAF) Testbed Baseline (OTB), Combat^{XXI}, Infantry Warrior Simulation (IWARS), Objective OneSAF (OOS), modified Combat^{XXI} (Mod Cbt^{XXI}), modified IWARS (Mod IWARS), modified OOS (Mod OOS), enhancement of and linkage between Combat^{XXI}, IWARS, and OOS (Combination), and creating a new simulation (New Sim). It should be noted that, since OOS is being developed to replace Janus, JCATS MOUT, and OTB, we refined the Combination alternative to consist only of the three simulations under development (Combat XXI, IWARS, and Objective OneSAF).

	Alter STMS Charac-teristics? (Yes)	Enter Scenario? (Yes)	HLA Compliant? (Yes)	Soldier Resolution? (Yes)	Aggregate to Platoon? (Yes)	Closed Loop? (Yes)	Recap	Alternative Category
ABMs	NG	G	NG	G	G	G	NG	
CASTFOREM	G	G	NG	G	G	G	NG	
Janus	G	G	G	G	G	G	G	1
JCATS	G	G	G	G	G	G	G	
OTB	G	G	G	G	G	G	G	
SSE	G	G	G	G	G	NG	NG	
VIC	G	G	G	NG	G	G	NG	
AWARS*	G	G	G	NG	G	G	NG	
Combat XXI*	G	G	G	G	G	G	G	2 & 3
IWARS*	G	G	G	G	G	G	G	
OOS*	G	G	G	G	G	G	G	
Combination	G	G	G	G	G	G	G	4
New Simulation	G	G	G	G	G	G	G	5

Figure 3.1: Feasibility Screening Matrix.

3.3 The Scoring Process

In order to evaluate each of the alternatives relative to the others, we applied a value-focused approach to provide a system that would facilitate this comparison. To this end, we developed a functional hierarchy that, at its highest level, focused on the simulation capability and decision support. After identifying lower-level functions within those two branches, we determined objectives for each lowest level function, which we defined for our purposes as the desired direction of attainment for an evaluation consideration (Kirkwood 1997). For each objective, we then selected an evaluation measure that would allow us to measure the degree of attainment of that objective. Because of the subjective nature of our system requirements, most of our evaluation measures were defined in terms of constructed scales, each level indicating an incremental change in the attainment of that objective.

Once the hierarchy was complete, we assigned local weights (LW) to the functions and objectives based upon the needs and desires of our client. These local weights indicate the value of that function or objective versus others on the same branch and level and must sum to 1.0 (within each branch and level). We then derived the global weights (GW) for each of the evaluation measures. The global weights indicate the relative stakeholder value of each of the evaluation measures with respect to the others and sum to 1.0 across the entire hierarchy. Figure 4.2 reflects the completed value hierarchy.

To facilitate a consistent comparison and differentiation between alternatives, we developed a conversion method (usually a curve) for each evaluation measure to convert a raw score into a value-score between 0 and 100, with 100 being the most desirable. It should be noted that we applied a fairly subjective process for determining raw values based on our constructed scales. This was necessary because many of our alternatives were under development or did not exist at all, which required performance estimates based on existing documentation, projected capabilities, and subject-matter

expertise. Subsequent to the generation of raw scores and conversion to values scores, we multiplied the respective global weights by the value scores and summed across all eight evaluation measures. This yielded a total value score for each alternative, the highest of which reflected the best available alternative.

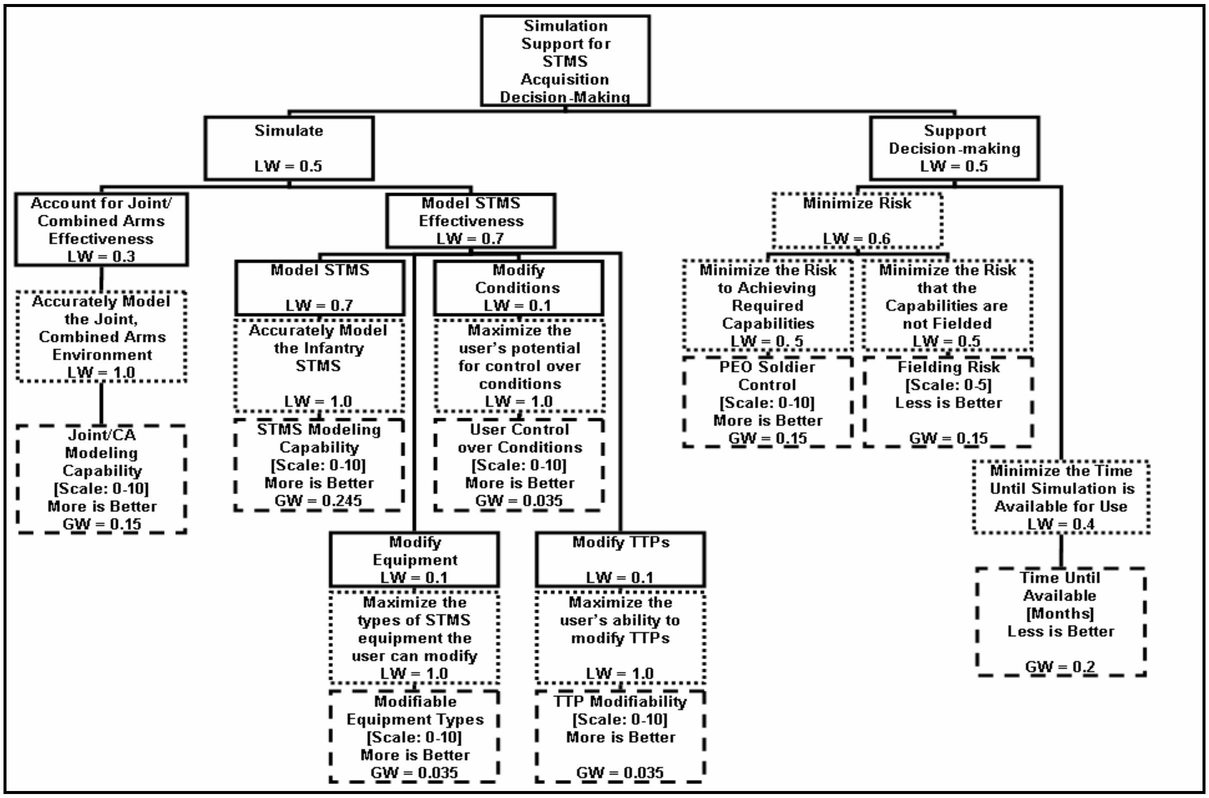

Figure 4.2: The Value Hierarchy that reflects the functional hierarchy down to lowest level functions with the respective objectives and evaluation measures.

4. RECOMMENDATION AND IMPLEMENTATION

4.1 Recommended Course of Action for PEO Soldier

As a result of our alternative scoring process, the Combination alternative (consisting of enhancements to and linkages between Combat^{XXI}, IWARS, and OOS) yielded the highest value score and thus merited selection as the alternative of choice. Moreover, since our weighting criteria and scoring scales were quite subjective, we conducted considerable sensitivity analyses on our results. From these analyses, we concluded that our recommendation was not sensitive to shifts in the local/global weights as assigned or to shifts in the constructed scales we applied.

As a secondary measure of assessment, we conducted an informal cost-benefit analysis between alternatives. We omitted total cost in our value hierarchy because we treated it as an independent variable. As with the other modeling we conducted, the determination of costs for alternatives that are still under development or not in existence was imprecise, at best. Thus we were only able to conduct an order-of-magnitude analysis. The alternatives generally fell into three primary groups: low-cost (existing simulations and simulations under development), mid-cost (modifying and/or combining existing simulations and simulations under development), and high-cost (developing a new simulation). Since creating a new simulation was both orders-of-magnitude more costly and provided less benefit, it was dominated by the highest-scoring alternative. Also, the Combination alternative fell within the same cost category of the closest-scoring alternatives, and, therefore, should not be ruled out due to costs. Thus, the Combination alternative became our recommended solution.

4.2 Implementing the Course of Action

On May 14, 2004, we presented our recommendation to PEO Soldier. That organization accepted our analysis, assessment, and resulting recommendation at that time. This signaled the transition from a decision-making phase to an implementation phase wherein we and PEO Soldier look to the future to identify a plausible and effective path forward. To that end, our study team has since worked

closely with PEO Soldier to identify the initial steps and to craft a path forward.

The first of these steps involved the delineation of the key tasks necessary to achieve implementation. These tasks will serve to set the conditions for successful implementation and include 1) the establishment of liaisons between PEO Soldier and simulation proponents which is critically necessary to ensure communication between parties and the clear articulation of respective needs, 2) identification of budgetary constraints and/or parameters, 3) negotiation of Memorandums of Agreement and Understanding (MoA, MoU) which facilitate a clear assignment of responsibilities and expected contributions, and 4) the development of a clear plan to execute and supervise simulation development. The next step, which is currently underway, involves presenting the concept and the supporting analysis to all parties involved, to include higher level decision-makers in the Army. The purpose of these presentations is to articulate the course of action, obtain concurrence and support, and to determine collaboratively the most appropriate and timely means to implement the solution. Finally, the path forward will include the identification and establishment of measures to serve as assessment metrics and controls for implementation. Such metrics will assist PEO Soldier and simulation proponents in effectively and successfully reaching their joint desired endstate; a fully-functional simulation capability that facilitates comparative analyses in support of acquisition decision-making.

5. CONCLUSIONS

PEO Soldier approached us with a broad, challenging problem with a relatively short suspense. The application of a comprehensive systems engineering approach provided us with a repertoire of tools and techniques that enabled us to decompose thoroughly and analyze the problem and then craft a solution in that short period of time. Consequently, we were able to present PEO Soldier with a robust recommendation that they have accepted and begun to implement in earnest. The enhancements to and linkages between Combat^{XXI}, IWARS, and OOS offer PEO Soldier the greatest benefit with respect to simulation capabilities and decision support.

Ultimately, the Combination alternative seems like a logical result. First, each of the three simulations involved possesses unique strengths that, when combined, should yield a tremendous synergy within the ensuing federation. In short, where one simulation may have weaknesses, another simulation may have strengths to counterbalance those shortcomings. Second, PEO Soldier support for initiatives already under way exploits a window of opportunity to alter the direction(s) of those initiatives to meet PEO Soldier's needs. Likewise, it facilitates the conservation of scarce resources (time and money) and helps to leverage valuable work already invested. Such support also benefits the simulation proponents themselves by lending value-added to their efforts and offering an opportunity to expand their application areas.

In the end, the greatest benefactor of this endeavor will prove to be the current and future Infantry soldier. With a greatly-enhanced capability to simulate soldier tactical mission systems, PEO Soldier and other members of the acquisition community can more effectively and quickly design, construct and field quality systems. These systems will then enable Infantry soldiers and units to exploit such technological advantages more effectively and efficiently and thereby enhance their success on the battlefield. Clearly, this recommendation and the initiatives to implement it will benefit all involved.

6. ACKNOWLEDGEMENTS

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